I. C. 6938

MARCH 1937

DEPARTMENT OF THE INTERIOR

UNITED STATES BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

SOME CAUSES OF BLOW-OUTS DURING DRILLING AND MEANS OF PREVENTION, WITH SPECIAL REFERENCE TO THE GULF COAST REGION

Read before the American Petroleum Institute, Division of Production, Southwestern District, Dallas, Tex., April 2, 1937.

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BY

CHARLES B. CARPENTER

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SOME CAUSES OF BLOW-OUTS DURING DRILLING AND MEANS OF PREVENTION, WITH SPECIAL REFERENCE TO GULF COAST REGION[1]

By Charles B. Carpenter[2]

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[2] Petroleum engineer, U. S. Bureau of Mines, Dallas, Texas.

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INTRODUCTION

When a drilling well strikes a horizon in which there is a large volu of petroleum or natural gas under high pressure, danger of a blow-out with disastrous results is imminent unless proper precautionary measures are taken. The history of oil-well drilling has been marked by many blow-outs and wild wells, some of which have caught fire and burned for long periods Such incidents nearly always make headline news, but ordinarily few person realize that what to them is an interesting newspaper item may entail grea financial loss to the operator and frequently loss of life or personal in- jury to members of the drilling crew and others in the vicinity of the wel

The blow-out, wild well, and crater are dreaded specters to every thoughtful person in the oil industry because of danger to life and proper ty, underground damage to surrounding wells, dissipation of reservoir ener and waste of irreplaceable natural resources that blow to the air or migrat to barren formations. Every operator drilling in high-pressure fields mus be on the alert always to forestall any conditions that may lead to a blow- out, and his vigilance must not cease until a well is completed and oil, g or both are flowing to storage or market.

The Bureau of Mines has published a number of reports in which vario factors pertaining to the control of high pressure wells have been stress and the literature contains other references giving extensive data to show that many imminent blow-outs can be controlled and the formation pressures

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3/ The list includes:

Arnold, Ralph, and Clapp, Frederick G., Wastes in the Production and Utili tion of Natural Gas and Means for Their Prevention: Tech. Paper 38, Bur of Mines, 1913, 29 pp.

Arnold, Ralph, and Garfias, V. R., The Prevention of Waste of Oil and Gas Flowing Wells in California, with a Discussion of Special Methods Used b J. A. Pollard: Tech. Paper 42, Bureau of Mines, 1914, 15 pp.

Heggem, A. G., and Pollard, J. A., Drilling Wells in Oklahoma by the Mud- Laden Fluid Method: Tech. Paper 68, Bureau of Mines, 1914, 27 pp.

McMurray, Wm. F., and Lewis, James O., Underground Wastes in Oil and Gas Fields and Methods of Prevention: Tech. Paper 130, Bureau of Mines, 191 28 pp.

Bowie, C. P., Extinguishing and Preventing Oil and Gas Fires: Bull. 170, Bureau of Mines, 1918, 56 pp.

Bell, H. W., and Cattell, R. A., The Monroe Gas Field, Ouachita, Morehouse and Union Parishes, La.: Bull. 9, Department of Conservation, State of Louisiana, in cooperation with United States Bureau of Mines, 1923, 43

Bell, H. W., Haury, P. S., and Kelly, R. B., Preliminary Report on the Eas Part of the Smackover (Ark.) Oil and Gas Field: Bureau of Mines and Sta of Arkansas, 1923, 43 pp.

Rison, C. O., and Bunn, John R., Petroleum Engineering in the Cromwell Oil Field, Seminole and Okfuskee Counties, Okla.: Bureau of Mines, Office o Indian Affairs, and State of Oklahoma, 1924, 39 pp.

Miller, H. C., Safe Practices at Oil Derricks: Tech. Paper 419, Bureau of Mines, 1927, 75 pp.

Hill, H. B., Crater Wells, Richland Gas Field, Louisiana: Tech. Paper 535 Bureau of Mines, 1932, 37 pp.

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pressed by a column of drilling fluid of adequate weight and consistency. ertheless, wells get out of control altogether too frequently, especially the Gulf coast region where the pressures in the deep-lying formations are her than in most fields of the United States.

The Bureau of Mines, believing that reduction of the number of wells of control depends on wider dissemination of information on the causes blow-outs and methods employed to prevent them, has prepared this report the use of those engaged, in any capacity, in the drilling of high-ssure oil or gas wells. Students of petroleum engineering also may d the report helpful as a guide to further study of the subject.

ACKNOWLEDGMENTS

This report was prepared under the direction of R. A. Cattell, chief ineer, Petroleum and Natural-Gas Division, Bureau of Mines. The writer efully acknowledges the assistance and suggestions given by Herbert Allen, eron Iron Works; Geo. G. Bloxsom, Baroid Sales Co.; Geo. E. Cannon, Humble and Refining Co.; J. H. Howard, J. H. McEvoy & Co.; Wm. V. Vietti, The as Co.; Don L. Cross, Accident Prevention Engineering Co. The writer also indebted to H. C. Fowler, H. C. Miller, H. S. Kennedy, H. B. Hill, Gustav e, W. B. Berwald, and R. K. Guthrie, all of the Bureau of Mines, for help- suggestions and criticisms.

DEFINITION OF TERMS

As the terms "blow-out", "wild well", and "crater" frequently are used hout strict distinction, the following definitions are given as an aid to ual understanding in the reading of this report:

A "blow-out" is a sudden expulsion of drilling fluid (mud, water, and etimes oil) followed by an uncontrolled flow of oil, gas, or water from uncompleted well that occurs when the pressure of oil, gas, or water ering the hole at some depth is greater than the pressure exerted by a umn of drilling fluid in the well.

A "wild well" is a well that is out of control and flowing oil, gas, or er without restriction as a result of a blow-out or failure of control ipment or casing. The gas and oil may become ignited, or a wild well entually may become a crater.

A "crater" is a basinlike opening in the earth's surface surrounding a ll caused by the erosive and eruptive action of the gas, oil, and water owing without restriction.

FORMATION PRESSURES

Petroleum and natural gas, as found in the earth, usually are confined der pressure in the pores of sedimentary rocks, such as sandstones and estones. In most types of producing structures the initial pressure of

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the oil or gas at a given level depends upon the difference between (1) the "head" of the water acting upward against the oil at the oil-water contact (or against the gas at the gas-water contact in structures that contain no oil) and (2) the "head" of the hydrocarbon fluids between the oil-water (or gas-water) contact and the given level. Structures in which the virgin pressure of the oil or gas at a given level is approximately equal to the hydrostatic pressure (depth in feet multiplied by 0.434 pound per square inch) of a column of water extending from the wellhead to that level are said to have "normal" pressures. Such pressures are to be expected if the porous rocks of the productive stratum are full of water between the oil-water (or gas-water) contact and an outcrop of that stratum at the approximate elevation of the wellhead, provided the head of the hydrocarbon fluids between the oil-water (or gas-water) contact and the given level does not differ greatly from the head of a column of water of equal height.

If the porous productive stratum crops out at an elevation that is lower than the wellhead, an oil or gas pressure less than the pressure of a column of water extending from the wellhead to the productive level is to be expected. Such pressures, termed "subnormal", are found in many producing areas. Conversely, in many structures the initial pressure of the oil or gas at a given level is "abnormal"; that is, it is greater than the hydrostatic head of a column of water from the wellhead to that level, often because the oil- and gas-bearing bed in the area outside its productive part is full of water to an outcrop that lies at a higher elevation than the wellhead.4/

Initial formation pressures for a number of fields in Texas, the hydrostatic pressure of a column of water for the corresponding depth, and the equivalent fluid pressure exerted by a column of drilling fluid weighing 10 pounds per gallon are listed in table 1.

METHODS OF DRILLING

High pressure oil and gas areas usually are drilled by the rotary method which consists of rotating a drill bit attached to the lower end of a string of drill pipe. Drilling fluid (mud-laden fluid) is circulated by means of "slush" pumps downward through the inside of the drill pipe and upward in the annular space between the drill pipe and walls of the hole until it reaches the surface and is discharged into the slush pits. The rotary method is so well-known in the industry and its essential details have been described so completely in the literature5/ that further description of the method in this report is not required.

4/ For a more complete discussion of pressure in producing horizons, see Cattell, R. A., and Fowler, H. C., Fluid-Energy Relations in Production of Petroleum and Natural Gas: Minerals Yearbook, 1934, Bureau of Mines, pp. 710-713.

5/ For example, see Uren, Lester Charles, Petroleum Production Engineering (Oil Field Development) 2d ed., McGraw-Hill Book Co., New York, 1934.
Jeffery, Walter H., Deep-Well Drilling: 3d ed., Gulf Publishing Co., Houston, 1931, 816 pp.
Brantly, J. E., Rotary Drilling Handbook: Russell Palmer Publication Inc., Los Angeles, 1936, 304 pp.

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TABLE 1. - Formation pressures for several Gulf coast fields

Company	Lease	Well no.	Depth at which pressure was observed, feet	Observed pressure, lb. per sq. in.	Equivalent hydrostatic pressure of water, lb. per sq. in.	Equivalent fluid pressure of drilling fluid (10 lb. per gallon), lb. per sq. in.
Humble	A.D.Middleton	3	7,045	3,190	3,057	3,663
	Cartwright	A-1	5,103	2,228	2,215	2,653
	So.Tex.Dev.	2	5,030	2,278	2,183	2,615
	do	5	5,158	2,207	2,239	2,682
J. K. Culton	Savage	2	4,020	1,528	1,744	2,090
Humble	J. F. Magale	3	8,010	3,775	3,476	4,165
	E. Maley	3	9,100	4,231	3,949	4,732
	Stewart	A-10	8,707	4,210	3,778	4,528
do	H. Edwards	1	6,624	3,026	2,874	3,444
Stanolind	A. Candelari	1	Casing-head	2/5,000	3,515	4,213
Average for 83 wells			6,035	2,731	2,619	3,138
	Bracey	A-5	3,525	532	1,530	1,833
Conroe	F. Bliss	1	5,700	2,537	2,473	2,964
Stanolind	J.C.Vann	1	4,705	2,172	2,041	2,447
	Bankers Mfg. Co.	B-2	3,725	1,665	1,617	1,937
	Camp	9	3,682	1,416	1,598	1,914
	Nelson	11	3,556	1,459	1,543	1,849
	F. I. Booth	1	5,156	2,291	2,238	2,681
	A. P. George	3	5,225	2,197	2,268	2,717

Hard, E. P., Control of High-Pressure Drilling Wells in the Gulf Coast: m. Petrol. Inst. Prod. Bull. 212, November 1933, pp. 76-82.
s well blew out while drilling at a total depth of 8,101 ft. Drilling fluid weighing 11 lb. per gallon was being circulated.

DRILLING FLUIDS

Functions of Drilling Fluids

The chief functions of a drilling fluid are:

1. To remove cuttings from the hole.

2. To hold solids in suspension when drilling is stopped.

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3. To provide a mud sheath on the wall of the hole, and thereby retard the infiltration of drilling water which causes caving and sloughing.

4. To seal off minor oil, gas, and water-bearing formations.

5. To suppress formation-pressures by the hydrostatic head of the fluid column.

6. To lubricate the bit and drill pipe.

7. To cool the bit.

Lawton, Ambrose, and Loomis[6] state:

Any drilling fluid may be regarded as a system of three main constituents: (1) water, (2) colloidal material, consisting of gel-forming and non-gel-forming colloids, and (3) larger particles suspended in the medium. Of the two types of colloid present, the gel-forming type is definitely the more important, for this group imparts the necessary properties of an efficient drilling fluid which are: (1) stability of suspension, (2) viscosity, (3) pore sealing, and (4) gel characteristics in general. Colloids of the nongelling type, together with larger particles, contribute somewhat to viscosity but more particularly to the density of the drilling fluid.

The word colloid means gelatinous, or resembling jelly. A colloidal state exists when one form of matter in a very fine state of division is distributed through a second phase. Colloids, according to a definition given in Drilling Mud Handbook,[7] are that division of substances wherein the solid particle aggregates range in size from a 0.000004 to 0.000000 inch. Colloids also have been defined as particles of matter that will pass through filter paper but will be retained by parchment paper. Characteristics of colloids that enable drilling fluids to perform their functions properly have been itemized in Drilling Mud Handbook[7] as follows:

1. Active colloidal material has the ability to become dispersed through many times its own weight of water, thus forming a viscous suspension which occupies a volume many times greater than that of the original solid.

2. The viscous suspension thus formed has the property of setting up into a gel or semiplastic solid when allowed to stand quiet for a short period of time. This gel quickly reverts to the fluid

6/ Lawton, H. C., Ambrose, H. A., and Loomis, A. G., Chemical Treatment of Rotary Drilling Fluids: Physics, vol. 2, no. 5, May 1932, pp. 365-375.

7/ Baroid Sales Co., Drilling Mud Handbook: Los Angeles, 1930, p.6.

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state when agitated but again assumes the semiplastic solid state when agitation or movement ceases. The term "thixotropy"[8] has been applied to the property of some materials to become more fluid as work is done on them but which will again lose their fluidity when quiescent.

3. Colloidal suspensions or suspensoids, as they are called, have a high viscosity for a low percentage of solids.

Natural clays vary widely in colloidal properties - a good grade of tural clay contains about 5 percent by weight of colloidal matter - and dinarily, it is necessary to add active colloidal matter to them to form suitable drilling fluid. Whenever positive control of the drilling . . . . uid is desired, mixtures of water, clay, and active colloidal matter are ployed, and increased density is attained when necessary by adding weight- g material.

Properties of Drilling Fluids

Virtually all information on drilling fluids is based on one or more the following physical properties,

1. Specific gravity or weight per unit volume.

2. Mechanical analysis of fineness of contained solids.

3. Consistency - which includes determinations of viscosity, plasticity, fluidity, mobility, yield point, and shearing strength.

The weight of a drilling fluid can be determined by weighing a given olume, usually 1 gallon, with a spring scale or by a special mud hydrometer ich measures the displacement of water when a small closed cup filled with illing fluid is submerged in a jar of water. Hydrometers of this type re graduated on the stem to read directly in pounds per gallon, pounds er cubic foot, and specific gravity. Determination of weight of drilling luids by the hydrometer method gives greater assurance of continued ac- uracy because spring scales frequently get out of adjustment and require requent calibration, whereas hydrometer readings can be checked readily y filling the cup with water instead of drilling fluid.

The quantity of noncolloidal solid materials in drilling fluids is etermined by mechanical analyses. Settling or centrifuge tests are usual rocedure, although coarse material frequently is screened. Marsh[9] has

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[8] Ambrose, H. A., and Loomis, A. G., Fluidities of Thixotropic Gels: Bentonite Suspensions: Physics, vol. 4, no. 8, August 1933, pp. 265-273.
[9] Marsh, Hallan N., Properties and Treatment of Rotary Mud: Am. Inst. Min. and Met. Eng., Petrol. Devel. and Technol., 1931, pp. 234-251.

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referred to the condition arising from the fact that United States Standa Sieve Series 325 is the finest sieve ordinarily available. The sieve wit this number designation has a size of opening of 44 microns (sieve openin of 0.044 mm or 0.0017 inch.)[10], and the maximum size of colloidal partic has been determined to be about 0.0001 millimeter or 0.ØØØØØ4 inch. The fore, material passing through this size of sieve likely will remain in s pension indefinitely.

The consistency of drilling fluids usually is expressed in terms of viscosity or plasticity. Viscosity is the resistance offered by a fluid the relative motion of its particles. Torsion- and funnel-type viscosime are used to measure the viscosity of drilling fluids. Viscosimeters of t torsion type, such as the Stormer, measure the torque or rate of shear by tating the liquid in a concentric cylinder at a given rate. Generally, i is desirable to maintain a viscosity of the drilling fluid of about 15 ce poises at 10 revolutions per second, as measured by a Stormer viscosimete The Marsh funnel-type viscosimeter[11] gives a measure of kinematic viscos of drilling fluids, but viscosity readings so obtained, and expressed in terms of cubic centimeter-seconds, have no direct relation to viscosity d terminations by the Stormer viscosimeter, measured in centipoises. Although viscosities determined by the funnel-type viscosimeter are only relative, the practicability of this instrument has led to its common use at drilling wells. Because the procedure of measuring viscosities with t Marsh funnel varied widely, making comparisons of drilling-fluid viscosi difficult, a group of petroleum engineers working in the Gulf coast regio of Texas in 1936 recommended:

> Whenever the drilling-fluid viscosities are determined with the Marsh funnel, 1,500 cubic centimeters of drilling fluid will be poured into the funnel, and the time required for the out-flow of 1,000 cubic centimeters will be measured in seconds.

For a mud weighing 10 pounds per gallon, the time of outflow should about 35 seconds. This agreed method permits some comparisons of drilli fluids.

Marsh[11] has summarized the main distinction between a fluid — com defined as a substance that will yield continuously to any force, no mat how small, if given sufficient time — and a plastic, which yields only a limited amount until the applied force exceeds some critical value. Ordi narily, possession of a yield point may be taken as a criterion of plasti In drilling fluids, this means that as long as the drilling fluid is in a fluid state cuttings will settle out, but when it is plastic cuttings wi not settle out. It is desirable for a drilling fluid to have both attri In explanation, when an interruption to drilling causes the drilling flu to be at rest in the drill hole, it should be in a plastic state to preve cuttings from settling out, as these might stick the drill pipe. On the

10/ A.S.T.M. Designation E11-26, Sieves for Testing Purposes.
11/ Marsh, Hallan N., work cited. (see footnote 9).

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her hand, when the drilling fluid is passing through the settling ditch should be in a fluid state so that the cuttings will settle out rapidly. e velocity of the fluid in motion in the hole tends to keep the cuttings om settling.

Good drilling fluids containing clay have predominating fluid characteristics when in motion and are plastic when at rest. The change from a uid to a plastic is due to gel-forming colloidal matter present. The degree of plasticity or gelation is called the gel strength. As stated, ixotropy is a property of some materials which enables them to become uid when work is done on them and to lose fluidity when quiescent. Bentonite[12] clay that is high in colloidal matter, is used in drilling fluids to produce ixotropic gels. According to Bingham[13], the gel structure requires time o form, and the fluidity at a given moment depends upon the recent history.

No instruments for measuring the gel strength of drilling fluids have een devised, but relative values can be obtained from determinations of iscosity made by either the Stormer or the Marsh funnel viscosimeter. or example, the viscosity of a sample of drilling fluid can be determined s it comes from the flow line and again after it has been allowed to stand or 5 minutes; the difference between the two viscosity determinations gives n indication of the rate of gelation or the gel strength.

CAUSES OF BLOW-OUTS

Inadequate Weight of Fluid Column

When a drill bit reaches gas- and oil-bearing strata under high pressure, he suppression of formation-pressures becomes the most important function of drilling fluid, and its weight should be controlled carefully.

Water weighs 8.33 pounds per gallon, and a column of water 1 foot high xerts a pressure of 0.434 pound per square inch at its base. A drilling luid weighing 10 pounds per gallon (specific gravity, 1.2) exerts a pressure f 0.52 pound per square inch per foot of height and generally will control ll normal formation pressures with a margin of safety.

Drilling fluids usually are made by mixing natural clays with water, he weight of the mixture depending on the quantity of clay used. Sometimes, owever, the natural clays penetrated while drilling are deficient in desirable qualities or are lacking in quantity, and commercial clays must e obtained to make up the deficiencies. The average specific gravity of lay is 2.4; that is, a unit volume of clay weighs 2.4 times a unit volume f water. One barrel of drilling fluid composed of natural clay and water, eighing 10 pounds per gallon, contains approximately 0.15 barrel of clay and .85 barrel of water.

12/ Davis, C. W., and Vacher, H. C., Bentonite, Its Properties, Mining, Preparation, and Utilization: Tech. Paper 438, Bureau of Mines, 1928, 51 pp.

13/ Bingham, E. C., Fluidity and Plasticity: McGraw Hill Book Co., New York, 1922, p. 198.

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The assertion that a drilling fluid of proper weight per gallon will control safely a designated formation pressure assumes that the hole will be kept full of drilling fluid of uniform weight. If the fluid level is lowered or the weight of the drilling fluid decreased, the pressure exerted by the fluid column at its base is reduced accordingly. The level of the drilling fluid may be lowered by withdrawal of drill pipe, bailing or swabbing, or by infiltration of water making up the drilling fluid into subsurface formations or leakage of the fluid into crevices and caverns. When the formation pressure at any depth in a well approaches the corresponding hydrostatic pressure of a column of water, a slight lowering of the fluid level may be sufficient to upset the pressure balance and cause the drilling fluid to be blown from the hole.

Drilling fluid is displaced when drill pipe is run into the hole, and conversely the level of the drilling fluid is lowered as the drill pipe is withdrawn. Drill pipe of 4-1/2-inch outside diameter will displace 11 cubic feet of fluid per 100 feet of pipe (see table 2), and the fluid level in a 9-inch diameter hole (see table 3) will be lowered 33 feet by the withdrawal of 100 feet of 4-1/2-inch outside-diameter drill pipe. The volume of drilling fluid inside of the drill pipe may be disregarded because it usually flows out of the openings in the drill bit so slowly that a large part is lost on the derrick floor as each stand of pipe is disconnected. The withdrawal of a stand of 4-1/2-inch outside-diameter drill pipe 90 feet long from a 9-inch-diameter hole will lower the fluid level 33 x 0.9 or 29.7 feet (see table 3), and will reduce the fluid pressure 29.7 x 0.52 or 15.4 pounds per square inch. Therefore, it is advisable, especially when drilling in high-pressure zones, to fill the hole with drilling fluid after every three stands of pipe have been withdrawn.

If the drilling fluid has low viscosity and low gel rate, the cuttings frequently settle out and pack around the drill bit or drill-pipe collars when circulation is interrupted, and when the drill pipe is withdrawn, a swab action is induced which may cause drilling fluid to flow out of the hole and reduce the pressure of the column by 90 x 0.52 or 47 pounds per square inch for each stand of drill pipe withdrawn. Swab action not only lifts drilling fluid from the hole but also permits gas from the formation to fill the evacuated part of the hole below the drill bit. When the swab action has ceased, the drilling fluid drops to the bottom of the hole; the gas that was drawn in mixes with the drilling fluid and displaces an equivalent volume of drilling fluid and thereby lightens its weight. (See following example). Although the pressure exerted by the column of drilling fluid is greater than the formation pressure, the gas drawn in by swab action probably will not be forced back into the formation when the drilling fluid drops into the gas-filled space at the bottom of the hole. As discussed later in this report, swab action also may be caused by using a drilling fluid of high gel-strength, especially in wells where the annular space between the drill pipe and the casing or hole is small.

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TABLE 2. - *Capacities of holes and volumes displaced by drill pipe* I. C. 6938

	Volume displaced	Inside diameter of hole or pipe, inches											
		4	5	6	7	8	9	10	11	12	13	14	15
Area of hole or pipe, sq. in.		12.56	19.63	28.27	38.48	50.26	63.61	78.53	95.03	113.09	132.73	153.94	176.71
Area of hole or pipe, sq. ft.		.087	.136	.196	.267	.349	.441	.545	.659	.785	.921	1.069	1.227
Approx. volume of hole or pipe per 100 feet, cubic feet		8.7	13.6	19.6	26.7	34.9	44.2	54.5	66.0	78.5	92.2	106.9	122.7
Approx. volume of hole or pipe per 100 feet, gallons		65.1	101.6	147.0	199.5	260.8	330.5	407.4	493.5	587.2	689.6	799.7	917.7
Approx. volume of hole or pipe per 100 feet, barrels		1.55	2.42	3.5	4.75	6.21	7.87	9.7	11.75	13.98	16.42	19.04	21.85
Approx. volume displaced by 100 feet of 6 5/8 in. O. D. drill pipe, cubic feet	23.93												
Approx. volume displaced by 100 feet of 6 5/8 in. O. D. drill pipe, barrels	4.26												
Approximate volume displaced by 100 feet of 4 1/2 in. drill pipe, cubic feet	11.04												
Approx. volume displaced by 100 feet of 4 1/2 inch drill pipe, barrels	1.96												
Approx. vol. displaced by 100 feet of 3 1/2 inch drill pipe, cubic feet	6.7												
Approx. vol. displaced by 100 feet of 3 1/2 inch drill pipe, barrels	1.19												

	Sq.in.	Sq. ft.
Area of 6 5/8-inch O. D. drill pipe =	34.47	= 0.239
Area of 4 1/2-inch O. D. drill pipe =	15.90	= .110
Area of 3 1/2-inch O. D. drill pipe =	9.62	= .067

1 barrel (42 gallons) = 5.614 cubic feet

1 cubic foot = 7.48 gallons

A column of pure water 100 feet in height exerts a pressure of 43.4 pounds per square inch.

A column of drilling fluid (sp. gr. 1.2 - 10 lb. per gal.) 100 feet in height exerts a pressure of 52 pounds per square inch.

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	Inside diameter of hole or pipe, inches										
	5	6	7	8	9	10	11	12	13	14	15
Maximum reduction in height of fluid column due to withdrawal of 100 feet of 6 5/8-inch O. D. drill pipe, feet					118.0	78.0	57.0	44.0	35.0	29.0	24.0
Maximum reduction in fluid pressure due to withdrawal of 100 feet of 6 5/8-inch O. D. drill pipe (sp. gr. drilling fluid 1.2), pounds per square inch					61.0	40.0	29.0	23.0	18.0	15.0	12.0
Maximum reduction in height of fluid column due to withdrawal of 100 feet of 4 1/2-inch O. D. drill pipe, feet			70.0	46.0	37.0	25.0	20.0	16.0	14.0	12.0	10.0
Maximum reduction in fluid pressure due to withdrawal of 100 feet of 4 1/2-inch O. D. drill pipe (sp. gr. drilling fluid 1.2), pounds per square inch			36.0	24.0	17.0	13.0	10.0	8.0	7.0	6.0	5.0
Maximum reduction in height of fluid column due to withdrawal of 100 feet of 3 1/2-inch O. D. drill pipe, feet	96.0	52.0	34.0	24.0	18.0	14.0	11.0	9.0	8.0	7.0	6.0
Maximum reduction in fluid pressure due to withdrawal of 100 feet of 3 1/2-inch O. D. drill pipe (sp. gr. drilling fluid 1.2), pounds per square inch	50.0	27.0	18.0	12.0	9.0	7.0	6.0	5.0	4.0	4.0	3.0

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To illustrate the effect of swab action, assume a 9-inch diameter hole eing drilled at a depth of 5,000 feet, a formation pressure of 2,100 pounds er square inch (143 atmospheres), and a drilling fluid weighing 10 pounds er gallon. The volume of the hole evacuated by the withdrawal of one stand 90 feet) of 4 1/2-inch O. D. drill pipe and the evacuated space at the bot-om of the hole filled simultaneously with gas at a pressure of 143 atmos-heres is 0.441 x 90 = 39.7 cubic feet, which, if expanded from 143 atmos-heres to atmospheric pressure at the surface, will occupy a volume of 39.7 143, or 5,677 cubic feet. The volume of drilling fluid displaced by gas s it rises through the column will be $\frac{39.7 + 5,677}{2}$ = 2,858 cubic feet. The otal volume of drilling fluid remaining in the 4,910 feet of hole after the 0 feet of hole below the drill bit has been freed of drilling fluid is 44.2 11.04 = 33.16 x 49.10 = 1,628 cubic feet (table 2); this volume is 2,858 - ,628 = 1,230 cubic feet less than the volume of gas in the hole, and a blow-ut would occur when the gas became dispersed throughout the column of drill-ng fluid. To preclude the danger of inducing swab action when drilling hrough a gas zone, circulation should be maintained for 30 minutes to 1 our, with the drill pipe rotating several feet off bottom, before the first tand of pipe is slowly withdrawn. It is desirable also to resume circula-ion for a few minutes after the withdrawal of every third or fourth stand f pipe.

Although gas enters the hole as a result of swab action induced by the oo rapid withdrawal of drill pipe, it may not rise in the column until the rill pipe is lowered again in the hole and the drilling fluid again dis-laced and agitated. It is true that most blow-outs occur while drill pipe s being withdrawn from the hole, but their occurrence when drill pipe is eing lowered in the hole is not uncommon.

Pressures in some porous formations exceed the normally expected pres-ure because extraneous gas from a lower formation has migrated upward and urcharged the stratum as the result of well blow-outs or improperly cased ells. Regardless of the cause, when a pressure greater than that exerted y a column of water of a height equal to the depth of the reservoir sand s found, the weight of the drilling fluid must be increased to more than 10 ounds per gallon.

The weight of a drilling fluid can be increased to approximately 10 ounds per gallon by the addition of natural clays, but if a greater weight s required "weight material" must be added. Weight materials commonly used onsist of finely pulverized minerals, such as barites and iron oxide, of igh specific gravity, ranging from 2.6 to 4.5. By the addition of weight a'erials, drilling fluids can be increased in weight to as much as 20 pounds er gallon, or two and one-half times the weight of water.

The quantity of weight material that can be added to a drilling fluid epends upon the viscosity and gel-forming colloids of the original drilling luid. If the viscosity already is high, the addition of weight material ay cause an increase in viscosity that will impede circulation and make

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the drilling fluid vulnerable to gas cutting. On the other hand, if the d ing fluid has a low content of gel-forming colloids, the added weight mate will have a tendency to settle out whenever circulation is stopped.

Drilling fluids may become diluted with water while being mixed or w being transferred from one pit to another by means of a steam jet, or rai water may dilute them if the slush pits are not sheltered. Dilution with water may reduce the weight of the drilling fluid enough to render it ine fective in suppressing high formation pressures.

The weight of drilling fluid cannot be determined by inspection in t ditch; a fluid that appears to be heavy may be merely thick or viscous an may weigh less than water. Because the composition and weight of the dri ing fluid are changing constantly during drilling, drillers should deter the specific gravity of the drilling fluid at frequent and regular inter and any reduction in weight should be investigated promptly. The weight the drilling fluid should be ascertained at the point of discharge from t flow line and also near the suction side of the pump.

Loss of circulation through crevices or fissures in reservoir format larger than the ordinary pore spaces of the rocks may cause a sudden redu tion in the height of the fluid column, that is sufficient to permit a blo out. As the size and extent of crevices or fissures cannot be determined from surface observations, some substance that will seal them quickly mus be introduced into the drilling fluid to prevent loss of fluid. Lime and chemicals are used to flocculate (collect in soft flakes) drilling fluids with the view that the flocculent precipitate will seal the openings. In extreme cases cottonseed hulls, chopped rope, and straw have been added t the drilling fluid and circulated in the well.

Improper Consistency of Drilling Fluids

Drilling fluids should be thoroughly mixed before they are circulat in the hole to assure uniform distribution and wetting of the colloidal weighting materials. Thorough mixing is a primary requisite for the pre of blow-outs. Wherever possible colloidal and weighting materials shoul mixed initially by a jet-type mixer.

Significance of Viscosity

The viscosity and gel-strength of a drilling fluid furnish the best indices of consistency and are extremely important factors in the preven of blow-outs.

Drilling fluids that are too viscous require high pump pressures to tain circulation, hinder rapid settling of cuttings in the ditch, and te become "gas-cut". Free circulation of drilling fluid in the well is ess for the effective removal of cuttings from the bottom of the hole and th proper lubrication of the drill pipe. When the circulation is retarded high viscosity, cuttings tend to collect near the bottom of the hole and

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illing progress. Cuttings carried from the hole by a highly viscous drilling fluid are held in suspension so tightly that they do not settle out during the time required for the circulating fluid to pass through the ditch; consequently they are recirculated in the hole.

The viscosity of a drilling fluid may be increased because of colloidal material in the natural clays penetrated while drilling or by the addition of commercial colloidal matter, such as bentonite (a natural hydrous silicate of alumina containing about 90 percent of gel-forming colloidal matter) or chemicals. Loss of water from the drilling fluid due to infiltration into the walls of the hole and increase in temperature also tend to increase the viscosity of drilling fluids.

The viscosity of a drilling fluid may be reduced by dilution or thinning with water and by the addition of chemicals.

"Gas-Cut" Drilling Fluid. - Drilling fluid intermixed with gas is said to be "gas-cut". Gas[14] can be intermixed with drilling fluid by simple mixture, absorption or solution of the gas in the drilling fluid, and adsorption on the surface of, or in the pores of, the solids in the drilling fluid. Drilling fluids of high viscosity ordinarily tend to become gas-cut; they release the entrained gas slowly in the ditches or at the surface and unless properly treated may be recirculated in the well while subnormal in weight. By maintaining a drilling fluid of low viscosity, admixed gas can be released, usually by vibrating screens or by allowing the drilling fluid to flow over baffles or in a thin layer through the ditches and slush pits. The drilling fluid also may be pumped through nozzles or sprays to aerate it and at the same time mix it more thoroughly. When the intermixture of gas and drilling fluid is due to adsorption, frequent replacement of the gas-cut drilling fluid with fresh drilling fluid is necessary.

The greatest danger in circulating a highly viscous drilling fluid is the tendency of such fluids to become lightened by "gas-cutting". Free gas in the voids of the rock being drilled becomes mixed with the drilling fluid as the bit penetrates gas-bearing strata, and the gas displaces its equivalent volume of drilling fluid. The volume displaced depends upon the porosity of the rock and the formation pressure. For example, in drilling a 9-inch-diameter hole through a gas sand having a porosity of 25 percent, each foot of hole drilled will contain a pore space or total voids of $0.441 \times 1.0 \times .25 = 0.1102$ cubic foot. If the pore space is filled with gas at a formation pressure of 2,100 pounds per square inch (143 atmospheres) the gas will expand to 143 times its volume, or 15.57 cubic feet when brought to the surface. The quantity of drilling fluid displaced by the gas depends upon the rate of circulation of the drilling fluid. If drilling progresses in a 9-inch hole at the rate of one-half foot per minute and the drilling fluid is circulated at the rate of 150 gallons per minute, every 150 gallons of drilling fluid will contain $\frac{15.57}{2}$ or 7.88 cubic feet of gas. In other words, each cubic foot of gas will be mixed with $\frac{150}{7.88}$ or 19.03 gallons of drilling fluid. Regarding the weight of the gas, 19.03 gallons of drilling fluid weighing,

[14] Baroid Sales Co., Some Factors Governing the Use of Weight Material in Drilling Wells: Drilling Mud: Los Angeles, vol. 1, no. 11, December 1933, pp. 1-7.

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for instance, 9.25 pounds per gallon, and 1 cubic foot (7.5 gallons) of gas will weigh 176 pounds and occupy a volume of 19.03 + 7.5, or 26.53 gallons at the surface. Each gallon of the gas-cut mud, therefore, will weigh $\frac{176}{26.53}$, 6.63 pounds — 2.62 pounds less per gallon than the uncontaminated drilling fluid. Since the drilling fluid is assumed to weigh 9.25 pounds per gallon as it is pumped from the drill pipe at the bottom of the hole and 6.63 pounds per gallon when it returns to the surface, the average weight throughout the column is $\frac{9.25 + 6.63}{2}$, or 7.94 pounds per gallon. In this example a blow-out would result because the formation pressure is 2,100 pounds per square inch, whereas the pressure exerted by a 5,000-foot column of drilling fluid weighing 7.94 pounds per gallon is $\frac{7.94}{8.33} \times 0.434 \times 5{,}000$, or 2,068 pounds per square inch. If the drilling fluid had weighed 10 instead of 9.25 pounds per gallon, the pressure exerted by a 5,000-foot column of gas-cut drilling fluid (by the same method of calculation) would have been 2,235 pounds per square inch, or 135 pounds per square inch more than the formation pressure and a blow-out would have been averted providing the gas was released from the drilling fluid at the surface.

Control of Gel Strength. - As previously stated, good drilling fluids containing clay have predominating fluid characteristics when in motion and are plastic when at rest. The change from the fluid to the plastic state is due to gel-forming colloidal matter, and control of the gel-strength of drilling fluids is highly important when drilling in high-pressure gas zones. Drilling fluids having a low rate of gelation and low gel strength are undesirable because solid materials may settle out when drilling is temporarily stopped or circulation interrupted. On the other hand, drilling fluids having high rates of gelation and high gel strength are objectionable because their close adherence to the drill pipe has a tendency to induce swab action when drill pipe is withdrawn.

The relation between gel strength and swab action was demonstrated by Cannon[15] in tests conducted to determine the magnitude of the pressure drop at the bottom of the hole when drill pipe is withdrawn. He observed a pressure drop of 150 pounds per square inch in a 7-inch casing at a depth of 5 feet when the gel strength of the drilling fluid was 3 units (arbitrary) and a pressure drop of 385 pounds per square inch when the gel strength was increased to 80 units (arbitrary).

Since no instruments have been devised for measuring the gel strength of drilling fluids, it is difficult to specify the proper limits for safe practice. One operator that uses Marsh funnel viscosimeters (pouring in 1,500 cubic centimeters of drilling fluid and observing the time of efflux for 946 cubic centimeters or 1 quart) has adopted the practice of observing the viscosity of a sample as it discharges from the flow line and again af-

15/ Cannon, Geo. E., Changes in Hydrostatic Pressure Due to Withdrawing Drill Pipe from the Hole: Am. Petrol. Inst., Drilling and Production Practice, 1934, pp. 42-47.

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:e sample has been allowed to stand for 5 minutes. If the difference between :e two viscosity observations is greater than 7 seconds, thinning the drilling :uid with water or chemicals is recommended.

According to Vietti and Levy,[16] the gel strength of a drilling fluid may : increased by the addition of gel-forming colloidal matter, lime, and caustic :da, sodium aluminate, or other alkaline or soluble metal salts and may be :creased by treatment with sodium tannate or sodium gallate and treatment with :osphates.

gnificance of Stability

The stability of clay dispersions in drilling fluids is a most essential :tor because it is imperative that weighting material and cuttings remain in :spension when in the hole. Fine particles, such as colloids, which are em-:oyed to suspend solid materials are precipitated by electrolytes. Hence, :en a drilling fluid composed of a dispersion of colloids comes in contact :th salt water, which is an electrolyte, the solids (cuttings and weighting :terial) tend to precipitate or settle out. It is sometimes necessary to :eat the water used in mixing the drilling fluid to reduce flocculation and :ecipitation. Some commercial clays are prepared especially to resist the :ecipitating action of electrolytes.

Experiments show that colloidal matter reaches a maximum dispersion when :e solution is slightly alkaline. The reaction of any solution, whether acid : alkaline, can be expressed in terms of a pH number, which is a measure of :e hydrogen-ion concentration. Any pH number from 0 to 7 indicates acidity, :th decreasing acidity as the number increases. A pH number 7 indicates :utrality and a pH number between 7 and 14 alkalinity which increases as the :mber increases. Experiments conducted by Ambrose and Loomis[17] showed a :ximum dispersion of Baroid (a commercial weighting material) in water at a : value of 10.5 to 11.5. Chemists and engineers measure the pH value of a :illing fluid with the Wulff pH tester and from these determinations they are :le to calculate what, if any, chemical treatment is necessary to obtain :ximum dispersion or stability. The Wulff tester utilizes color changes of :rips (containing an indicator) caused by the penetration of the hydrogen ion; :e pH value is ascertained by comparison of indicator strips with color :andards.

PREVENTION OF BLOW-OUTS

The two principal causes of blow-outs while drilling (inadequate weight :d improper consistency of the drilling fluid), together with corrective and :recautionary methods, have been discussed in foregoing sections of this report.

16/ Vietti, W. V., and Levy, A. G., Blow-Out Prevention and Control: Before Am. Petrol. Inst. Southwestern District Meeting, April 1935; published in Oil and Gas Jour., June 6, 1935, p. 15.

17/ Ambrose, H. A., and Loomis, A. G., Chemical Treatment of Rotary Drilling Fluids: Ind. and Eng. Chem., September 1933, p. 1019.

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A knowledge of the causes and prevention of blow-outs is of no avail, howe unless those engaged in drilling make practical application of it. Even w an understanding of the causes of blow-outs and diligent execution of safe drilling methods, it is necessary also to adopt certain preventive measure and retain a trained personnel.

Preventive Measures

These measures include the following mechanical equipment and appurte

1. Pressure-tested casing properly cemented.
2. High-pressure fittings.
3. Dependable blow-out preventers.
4. Quick-closing valves for flow line and drill pipe.
5. Large-capacity, high-pressure slush pumps.
6. Adequate power.
7. Ample supply of drilling fluid in reserve pits.

Pressure-Tested Casing

The casing in all wells should have tight joints and enough strength withstand static pressures greater than the pressure exerted by a column water for the depth to which the well is to be drilled. This means that smallest-diameter casing in a 5,000-foot well should be capable of withs a static internal pressure of 5,000 x 0.434, or 2,170 pounds per square and in a 7,000-foot well a static pressure of 7,000 x 0.434, or 3,038 po per square inch.

Casing is tested at the factory and the test pressure is stenciled outside of each joint. The test pressure usually is between one-third a fourth of the ultimate bursting pressure, depending on the factor of saf used. The ultimate bursting pressure of new pipe will be furnished by t manufacturer, or can be calculated by Barlow's formula which is,

$$p = \frac{2 f t}{D},$$

Where p = internal fluid pressure, lb. per sq. in.

D = outside diamter of pipe, inches

f = tensile strength of material, lb. per sq. in.

For A.P.I. Casing Grade A, f = 48,000 lb. per
Do. B, f = 70,000
Do. C, f = 75,000
Do. D, f = 95,000
t = average thickness of wall of pipe.

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orn or damaged casing should never be placed in a high-pressure well, and o second-hand casing should be used until it has been tested for pressures qual to or greater than the hydrostatic pressure for the proposed depth. string of casing set in a gas zone would be subjected to a pressure equivaent to the formation pressure (less the weight of the column of gas) if, rom any cause, the drilling fluid was totally expelled from the hole.

Surface control equipment should be fastened securely or anchored to the asing, and it is essential, therefore, that all casing be properly cemented. n wells drilled to low-pressure formations, enough cement is used, ordinarily, o bind together all strings of casing and to seal off the oil-producing zone rom the possible infiltration of water from upper strata. This practice, owever, is not safe in high-pressure wells, such as those drilled in the Gulf oast region. Each string of casing in high-pressure wells should be cemented rom its lower end to the surface, a procedure that will not only bind together ll strings of casing and seal off upper water strata, but will be good inurance against the upward migration of gas from lower high-pressure formations o upper low-pressure or to barren formations. By employing the multiple-tage method, cement can be placed as successfully behind long strings as beind short strings of casing. Wild wells expelling sand, small rocks, and ven boulders often result in "sand-cut", collapsed, or otherwise damaged asing which permits gas and oil to escape underground. Cement placed behind he entire length of each string of casing reduces this danger.

igh-Pressure Fittings

Every fitting, on the well, which is subjected to the maximum static presure should meet the requirements set out for the casing. Christmas trees sually are assembled in the shops where they can be tested by hydrostatic ressure before installation on the well. Machined flanges always should be sed; flanges made up with gaskets are more likely to leak and increase the azard of sand cutting.

Outlets to be used in flowing a well should be fitted with two valves n series, the downstream valve to regulate the flow and the upstream valve as stand-by shut-off if the downstream valve becomes damaged or cut by sand.

ependable blow-out preventers

When blow-outs occur with drill pipe in the hole the first drilling fluid o be expelled usually comes from the annular space because that drilling fluid s lighter than the drilling fluid that has been treated in the slugh pit and umped down the inside of the drill pipe. Occasionally, however, flow has been aused through the inside of the drill pipe by the withdrawal of a wire-line ore barrel. Blow-out preventers are attached to the top of the smallest-iameter casing in the well and are used to stop the flow of drilling fluid by ealing the annular space between drill pipe, casing, or tubing and the casing

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to which the blow-out preventers are attached. Some blow-out preventers a designed to grip and hold the pipe in a vise-like manner.

Blow-out preventers are of two types, packer and ram. Both types are signed to withstand pressures as high as 6,000 pounds per square inch. T packer type (sometimes called the Hosmer type after the original designer) consists of two units, a packer assembly with rubber between two split ri and a seating bowl attached to the top of the casing. To operate a packe type blow-out preventer, the packer assembly, which is held in readiness o the derrick floor, or in a mechanically operated inserter below the derri floor is latched around the drill pipe below the kelly joint and the dril pipe is lowered in the hole to seat and lock the packing assembly in the bowl. The packing assembly is expanded in the bowl by the weight of the drill pipe when the first coupling or tool joint comes to rest on the upp ring of the packing assembly. Automatic locking dogs hold the packing assembling in the bowl. Increase of well pressure in the annular space causes further expansion of the packing assembly and consequently a tight seal.

Since most packer-type blow-out preventers are closed by the weight drill pipe suspended in the hole when a coupling or tool joint becomes se on the packing unit, vertical movement or rotation of the drill pipe with blow-out preventers closed is usually impossible. A few packer-type blow preventers, however, maintain an effective seal against pressure while th drill pipe is being rotated, and recently a packer-type blow-out prevente was designed which seals automatically, accommodates itself to square or kelly joints, tool joints, and drill collars, and permits vertical moveme and rotation of the drill pipe.

Ram-type blow-out preventers close the annular space between the dri pipe and casing by forcing together two diametrically opposed rams which the pipe viselike. Rams may be obtained for any diameter of drill pipe, casing, or tubing. The concave metal surfaces of the rams are machined t fit the outside of drill pipe, casing, or tubing, and have grooves or re- cesses through which a highly resilient packing material is made to "flow by means of a self-feeding device. Due to the tremendous force applied b the rams, precaution must be taken to keep the pipe centered in the hole, any eccentricity of the pipe might result in failure of the rams to close crushing of the pipe between them.

Ram-type blow-out preventers can be operated manually, mechanically, by fluid pressure. When operated manually, each ram is forced against th drill pipe by turning a screw, which, for safety, should have an extensio stem at least 20 feet long fitted with a large hand wheel. Ram-type blow preventers may be operated mechanically by the rotation of an impulse whe mounted on the shaft of the driving device. The impulse wheel can be rot by a jet of steam or water from a nozzle.

In the pressure-operated ram-type blow-out preventer, which also can operated manually, the rams are actuated by pistons enclosed in two doubl acting pressure cylinders. Hydraulic pressure for operating the rams usu

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s supplied by boiler feed-water pumps. With the pressure equalized in both ylinders a quick-opening valve on the derrick floor enables the driller to pen or close the rams quickly.

Frequently, blow-outs occur with enough force to blow the drill pipe from e hole. Under those conditions the packer-type blow-out preventer, which is eated in the bowl by the weight of the drill pipe, would be ineffective for closing-in" the well. There are designs of ram-type blow-out preventers, owever, that have enough strength when gripped on the pipe to stop the upward ovement of the drill pipe and suspend it in the hole until the rams are released.

Most blow-outs occur when drill pipe is being withdrawn from the hole, nd since the pipe may be several hundred feet off bottom when the blow-out reventers are closed, complete circulation of drilling fluid (to the bottom f the hole) cannot be reestablished until the drill pipe is again lowered to ottom. The free movement of conventional drill pipe through closed blow-out reventers is obstructed by drill-pipe couplings, but by using two properly paced ram-type blow-out preventers in a well, conventional drill pipe can be aised or lowered safely by alternately opening and closing the blow-out preenters to pass the tool joints through them.

Ram-type blow-out preventers have certain advantages over packer-type low-out preventers in that they can be operated more easily while a well is lowing; and if the well is equipped with two ram-type blow-out preventers, onventional drill pipe can be raised or lowered with the well closed. Many perators, however, equip each drilling well with one ram-type blow-out preenter and one packer-type blow-out preventer.

All blow-out preventers should be inspected and tested regularly by the anufacturer.

ick-Closing Valves

Every drilling well should be equipped with one or more master gate alves to close the well when the drill pipe is out of the hole. If only one aster gate valve is used, the better practice is to place it above the blow-ut preventer; if two are used, one should be placed above and the other be-ow the blow-out preventer. Master gate valves should operate with ease nd be capable of withstanding as high pressure as the casing.

In addition to closing the annular space between the drill pipe and asing by blow-out preventers, it is necessary also to close the flow line nd the drill pipe to effect positive control of a well. The flow line sually is connected to a casing outlet below the lower blow-out preventer nd consequently is subjected to the full pressure of the well when the low-out preventers are closed. Flow-line valves, therefore, should meet he same pressure requirements as the casing and blow-out preventers, and n addition, should be positive and quick-closing. At some wells blow-outs ave occurred after the blow-out preventers were closed because of the failure of flow-line valves or the cutting action of sand flowing through a part-closed valve. Like blow-out preventers, flow-line valves may be operated

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manually or by fluid pressure; when operated manually they should be placed in the line at a safe distance from the well or should be equipped with extension stems and hand wheels.

Some drillers use back-pressure valves in the drill pipe below the swivel or kelly joint, but these are objectionable because they prevent the use of wire-line coring devices and increase frictional resistance. As previously explained, the drilling fluid in the annular space between the drill pipe and inserted casing or open hole will be expelled before the drilling fluid in the drill pipe; but after the annular space is closed, the drilling fluid will blow out of the drill pipe. Blow-outs occurring when the kelly joint is connected to the drill pipe can be controlled by pump pressure, but when the kelly joint is disconnected it is quicker to screw a "pup joint" or circulating head into the drill pipe suspended by the rotary table than to pick up and attach the kelly joint. The "pup joint", which is kept in readiness on the derrick floor at all times, consists of a piece of drill pipe with a tool joint pin on one end and a quick-closing high pressure valve on the other. If the well does not have master gate, the "pup joint" should be long enough to reach below the blow-out preventers so that they can be closed when there is no drill pipe in the hole. A swivel-type circulating head with rotary hose connected to the lower end of the standpipe provides a quick means of controlling the pressure and re-establishing circulation when the kelly joint is disconnected and drill pipe is suspended in the hole.

Large-Capacity High-Pressure "Slush" Pumps

All the functions of a drilling fluid, except that of suppressing for tion pressures, are performed by circulation, hence it is imperative that "slush" pumps have adequate capacity and pressure to meet any emergency. Ordinarily, circulation of drilling fluid in a well can be maintained by slush pump capable of delivering 200 gallons per minute at a pressure of 1,500 pounds per square inch. The total volume of drilling fluid in a 9- hole 5,000 feet deep is 16,525 gallons (see table 1); therefore to replac this volume, circulating at a rate of 200 gallons per minute, would requi $\frac{16,525}{200}$ or 83 minutes. One slush pump usually suffices for most drilling operations, but all thoughtful operators provide two pumps to insure cont circulation if one pump should fail or have to be shut down for repairs.

When two or more slush pumps are installed at a drilling well, it is practice to connect them directly with the standpipe and to manifold them instant compounding. This type of hook-up enables the driller to increas the pressure and rate of circulation at will to control a blow-out or kil well.

Adequate Power

When drilling through high-pressure oil and gas zones, adequate powe the continuous and simultaneous operation of drilling equipment and slush is extremely important. Interruption in circulation or rotation of drill

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en for short periods of time, may result in a blow-out or "frozen" drill e. The power required for drilling depends upon the depth of the hole, racter of the formation being drilled, size of drill pipe used, consistency drilling fluid, rate of circulation, and efficiency of the mechanical ipment. Since each of those factors is variable, the power required to erate a drilling well cannot be calculated exactly, but in most fields in e Gulf coast region three 125-horsepower boilers operating at a steam pres- re of 250 to 300 pounds per square inch are ample for all drilling and ergency purposes. For safety, boilers are placed on the windward side and a distance of 150 to 200 feet from the well. Boiler explosions cause ilers to be thrown either backward or forward, hence it is good practice set them at right angles to the direction of the well.

ple Supply of Drilling Fluid in Reserve Pits

The volume of drilling fluid in a rotary-drilled well usually increases drilling progresses, due to the admixture of natural clays in the forma- ons that are penetrated and the necessity of thinning the drilling fluid intervals with water. Consequently, it becomes necessary to transfer the cess drilling fluid to reserve pits. In most instances, inferior drilling id is transferred to the reserve pits; and no effort is made, in all elds, to recondition it unless circulation is lost, a blow-out occurs, replacement of drilling fluid in the hole becomes necessary because of s-cutting or the precipitating action of salt water. When additional mud required in a hurry it is usually necessary to stop drilling while re- nditioning the drilling fluid in the reserve pit or awaiting purchase and livery of commercial clays with which to make new drilling fluid. There- re, as a matter of safety and economy it is important to have in reserve ample supply of drilling fluid of the proper weight and consistency. en drilling is done in high-pressure gas zones the reserve supply should least be equal to the total volume of the drilled hole. The volume of e hole can be computed by referring to table 2, and the volume of the illing fluid in the pit can be determined by multiplying the area of the by the average depth of the drilling fluid.

Trained Personnel

The chief concern of every person engaged in drilling a well through gh-pressure formations should be to eliminate the causes of blow-outs by ntrolling the weight and consistency of the drilling fluid. They also uld be trained so that when a blow-out is imminent, they can command e first line of defense, and if possible, prevent its occurrence. This t be done successfully only through close coordination and teamwork.

Each workman should be warned of the dangers attending a blow-out and instructed in safe methods of prevention. Explanation of the design, notion, and operation of different kinds of preventive equipment should be cluded in the instruction, with special emphasis placed on its manipulation. ere is no substitute for actual practice as a means of learning to operate y mechanism, and daily drill periods for each crew of workmen are strongly commended. A "blow-out drill", as it is frequently called, serves to test

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all preventive equipment (blow-out preventers, flow-line valves, and pumps) and to furnish the workmen practice in its manipulation.

Blow-outs often occur when least expected, and quick action is necessa to prevent serious damage to well and equipment. To facilitate coordinatio each member of the drilling crew should be assigned to a post of duty to which he should go immediately when an alarm is sounded. The first step in preventing a blow-out in a drilling well is to close the blow-out preventer and flow lines, and the second, to start or increase the circulation of un-contaminated drilling fluid in the well. The exact procedure will depend o the type of blow-out preventers in use, design of pump manifold connections condition and quantity of the drilling fluid in the slush pits, and positio of the drill pipe and kelly joint at the time of the threatened blow-out.

Each "blow-out drill" should be pursued with as much diligence and dis patch as any other part of the drilling operations and should be fully exe-cuted. Regular practice will promote better teamwork and tend to eliminate confusion, which sometimes exists as a result of excitement and fright.

PREVENTION OF BLOW-OUTS WHILE RUNNING FORMATION TESTERS

Many blow-outs in drilling wells have been caused by swab action indu by the rapid withdrawal of formation testers after completing tests. A for tion tester, which consists essentially of an inlet valve with a packer ab is run into a well on the lower end of the drill pipe with the inlet valve closed. Before the inlet valve is opened to make a test, the packer must be set against the walls of the hole, above the point of test, to exclude the drilling fluid. After the test is completed the inlet valve is closed to retain the sample within the drill pipe, and the formation tester then is withdrawn from the hole.

To obtain an accurate test it is important that no fluid enter the drill pipe except when the test is being made; consequently, circulation cannot be resumed while the formation tester is in the well. Most forma-tion testers, however, have an equalizing by-pass valve above the packer which opens automatically after the inlet valve has been closed, thus perm ting the pressure to equalize above and below the packer. This equalizati of pressure facilitates the lifting of the packer and reduces the tendency toward swab action, but even so, it is imperative that the first few stan of drill pipe be withdrawn slowly and carefully when a formation tester is attached.

CONTROLLED OR PRESSURE DRILLING

Pressure-drilling equipment[18] offers the safest means of preventing blow-outs and controlling high pressures while drilling. The pressure-dri

18/ Parker, S. S., Pressure Drilling: Before Am. Petrol. Inst. Mid-Conti District Meeting, April 1935; published in Oil Weekly, Apr. 15, 19 pp. 23-26.

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thod consists of pressure regulation at the surface and usually requires the e of external flush-joint drill pipe with back-pressure valves, a drilling cker through which the drill pipe can be passed and rotated under pressure ith no loss of drilling fluid, oil, or gas), reverse slips, and a "snubbing " or "pull-down" unit for inserting the drill pipe into the hole against essure.

Although the use of the pressure-drilling method on the Gulf coast has en confined largely to drilling in fields where formation pressures were bnormal", it is adaptable to any pressure. One of the chief advantages of e method is that it permits drilling with a lower pressure at the bottom of e hole than the natural formation pressure, thus preventing drilling fluid om entering the formation. A well drilled under pressure also is ready to put on production as soon as the producing formation is entered by the ill bit.

PREVENTION OF BLOW-OUTS IN COMPLETED OIL AND GAS WELLS

The hazard of a blow-out in a well is not removed until the tubing is run d the Christmas-tree connected. Liners, screens, packers, and tubing are n in completed oil and gas wells with the hole full of drilling fluid, and or that reason, it is essential to circulate the drilling fluid thoroughly the well before final withdrawal of the drill pipe preparatory to running bing. Under no circumstances is it safe to run tubing, or set a liner and reen, without blow-out preventers or a stuffing box attached to the casing. veral blow-outs, wild wells, and craters have resulted from attempts to run bing in completed wells with no provision being made for blow-outs.

As a rule, blow-out preventers to fit all diameters of drill pipe and asing being used are furnished with each drilling rig, but because running bing sometimes is considered an unimportant task, blow-out preventers to t tubing are not always furnished. In the Gulf coast region where a screen sually is set in each well and it is necessary to wash both inside and out- ide of the screen to obviate clogging, extreme care at that time must be ex- rcised to avert a blow-out. "Washing-in" can be performed safely with blow- ut preventers, a tubing control head, or a Christmas tree and stuffing box pecially designed for use in setting liners, and screens and running tubing. hen either a tubing-control head or a stuffing box is used, it remains as ermanent equipment and enables the operator to raise, lower, or withdraw bing without "killing" the well.

SUMMARY

Initial formation pressures in the Gulf coast region are a little higher han "normal"; that is, they are greater than the equivalent hydrostatic pres- ure of a column of water. Normal formation pressures, and with few exceptions pressures encountered in Gulf coast fields, can be controlled with a margin f safety and blow-outs prevented while rotary-drilled wells are being "drilled n" by circulating a drilling fluid weighing approximately 10 pounds per gal- on (specific gravity, 1.2).

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Drilling fluids, which are composed of a mixture of water, colloidal material, and larger particles suspended in the medium, perform several functions, chief of which are removal of cuttings and gas from the hole, suppression of formation pressures while drilling, and lubrication of the drill pipe and bit. The ability of a drilling fluid to perform these functions depends upon two properties, weight (or specific gravity) and consistency. As the composition of the drilling fluid is constantly changi due to the addition of colloidal and noncolloidal material in the cuttings, close observation of the weight and consistency is necessary for accurate control.

The two principal causes of blow-outs while drilling are inadequate we of fluid column and improper consistency of drilling fluids. The control o normal formation pressures by a fluid column depends in large measure upon maintaining a hole full of drilling fluid of uniform weight. Strict atten- tion must be given to prevent lowering of the fluid column by withdrawal of drill pipe, infiltration, leakage, or swab action. Natural clays have an average specific gravity of 2.4, hence the weight or specific gravity of an mixture of clay and water will be greater than that of water. The weight o a drilling fluid can be increased to approximately 10 pounds per gallon by the addition of natural clays, and weights above 10 pounds per gallon are a tained by the addition of weighting materials. Reduction in weight is the result of dilution with water or of "gas cutting".

Consistencies of drilling fluids usually are expressed in terms of viscosity and plasticity (gel strength), both of which can be increased by the addition of active colloidal material or chemical treatment and can be decreased by dilution with water or chemical treatment. Highly viscous dri ing fluids retard circulation and become gas-cut more easily than those wit low viscosities. A good drilling fluid must have a low viscosity to allow release of gas and cuttings in the ditch and a gel strength that will make fluid when in motion and plastic when at rest.

Swab action incident to rapid withdrawal of drill pipe may be caused accumulation of cuttings around the drill pipe and bit or by a high-viscos high-gel-strength drilling fluid. The danger of inducing swab action can duced by circulating drilling fluid for 30 minutes to 1 hour prior to with the drill pipe from the hole, an operation that always should be performed

Stability of clay dispersions in a drilling fluid is extremely import since the fine particles or colloids are employed to suspend the solid mat Frequently this stability is disturbed by the precipitating action of elec and chemical treatment of the drilling water is required.

Despite every effort to eliminate the causes of blow-outs it is neces also to adopt certain preventive measures to control a well if a blow-out These measures include mechanical equipment, such as pressure-tested casin fittings, blow-out preventers, and valves, as well as ample drilling fluid able at high pressures.

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A trained personnel is a primary requisite for the prevention of blow-uts while drilling, and the importance of coordination and teamwork cannot overstressed.

The danger of inducing swab action when withdrawing a formation tester om the hole is greatly reduced by an equalizing bypass on the formation ster and slow withdrawal of the first few stands of drill pipe.

Pressure-drilling equipment, which to date has been used largely to ntrol "abnormal" pressures, offers the safest means of preventing blow-outs ring drilling.

Every well drilled to a high-pressure formation is a blow-out hazard til the Christmas-tree is connected, hence, the same precautions as are ed in drilling operations should be observed while running casing or ting and setting liners and screens.

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